Module - 4

A/D and D/A Converters

Digital to Analog Converters

→ The process of converting a digital data into an equivalent analog signal is known as Digital to Ananog conversion and circuits that converts data is known as DAC. (Digital to Analog converter).

→ The conversion circuit is n-bit parallel data such as 4 bit, 8 bit, 16-bit etc. each bit is either 0 or 1.

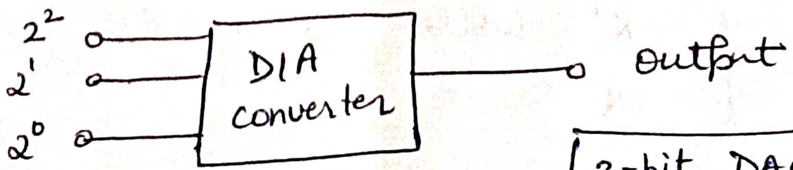
Two methods of Digital to Analog Conversion

i) Weighted Resistor D/A Converter

ii) R-2R Ladder D/A Converter

→ In both the methods each bit is connected to either 0 or 1 by using separate switches.

→ The o/p voltage of a D/A converter is made proportional to the equivalent binary weighted.



3-bit DAC

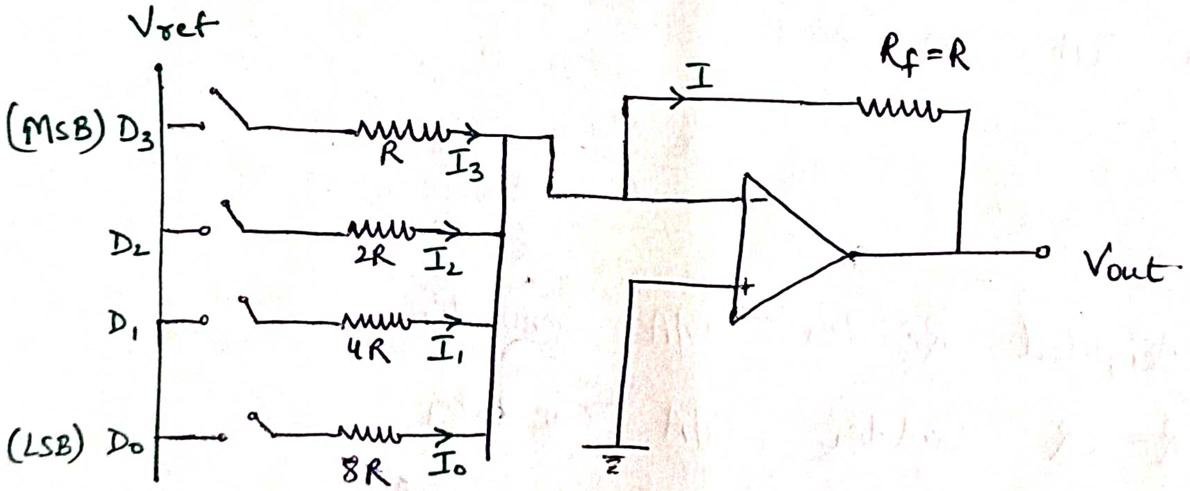
Weighted - Resistor D/A Converter

→ For each bit, signal is connected with weighted resistor.

→ The MSB input is connected with lowest resistor and towards LSB the resistance value is made twice of previous resistor.

→ The purpose of increasing the resistor value is to pass minimum current through LSB resistance while maximum current through MSB resistance.

→ The network connected in this method is also k/wn as "Variable Resistor Network"



4-bit Weightage Resistor D/A Converter with OPAMP

→ The circuit diagram of this D/A converter is a summing amplifier with four digital inputs D_3 D_2 D_1 D_0 with D_3 is MSB and weightage resistor of 'R' while D_0 is LSB with weightage resistor of 8R.

→ The input to the circuit can be connected by using four switches so that each switch can be either at 0 level or 1 level.

The output voltage of the D/A converter is given by -

$$V_o = -R_f \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4} \right] \quad \text{--- (Summing Amplifier)}$$

In this ckt, $R_f \approx R$, then

$$V_o = -R \left[\frac{D_3}{R} + \frac{D_2}{2R} + \frac{D_1}{4R} + \frac{D_0}{8R} \right] \quad \text{OR}$$

$$V_o = -R \left[\frac{V_3}{2^0} + \frac{V_2}{2^1} + \frac{V_1}{2^2} + \frac{V_0}{2^3} \right] \quad \text{[Formula]}$$

where

$D_3 = V_3$, $D_2 = V_2$, $D_1 = V_1$, $D_0 = V_0$

Let us take two voltage levels -
0 = 0V and 1 = 4V, let's find analog output for different combinations of inputs.

i) When input is $D_3 D_2 D_1 D_0$ = 0000

$V_o = 0$

ii) When input is $D_3 D_2 D_1 D_0$ = 0001

$$V_o = -R \left[\frac{0}{R} + \frac{0}{2R} + \frac{0}{4R} + \frac{4V}{8R} \right]$$

$$= -R \left[\frac{1}{2R} \right] V \Rightarrow \frac{-V}{2} = -0.5\,V$$

iii) When input is $D_3 D_2 D_1 D_0 = 0010$

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{4V}{4R} + \frac{0}{8R}\right]$$

$$\boxed{V_o = -1V}$$

iv) When input is $D_3 D_2 D_1 D_0 = 0011$

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{4V}{4R} + \frac{4V}{8R}\right]$$

$$\boxed{V_o = -1.5V}$$

→ These outputs shows that the output voltage of this DAC is proportional to its Digital input.

Drawbacks of Weighted Resistor DAC

a) Each resistor has a different value, which is exactly half of previous one. It requires wide range of resistors about R to $(2^{n-1} \times R)$ for n-bit.

b) Each resistor handles different value of current. So, all have different voltages.

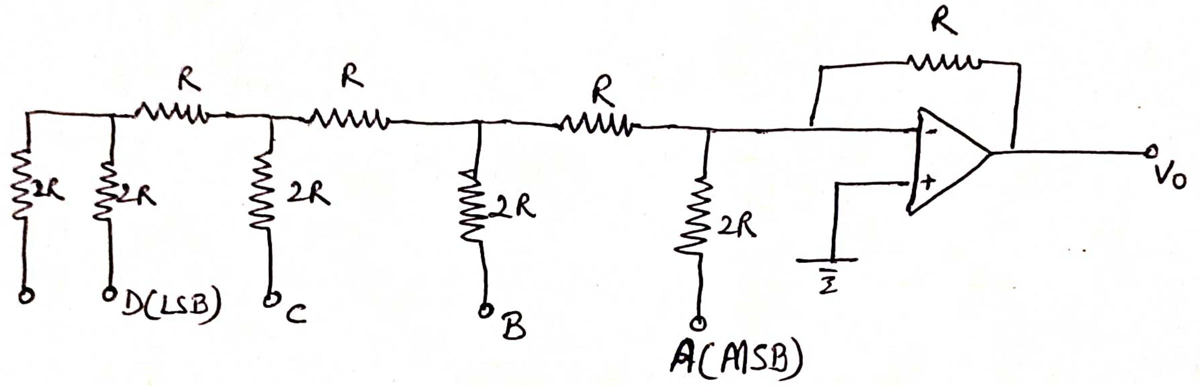
c) The MSB resistor requires to handle large current.

d) Any change in temperature will cause change in resistance, which will affect o/p voltage.

R-2R Ladder D/A Converter

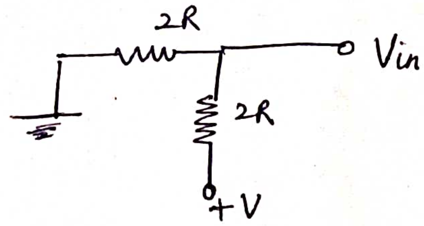
— It contains only two resistor values R and 2R.

→ It has a OPAMP as a scaling circuit and MSB i/p towards right and LSB i/p with left of the circuit. A 4-bit ladder type D/A converter is shown in fig.



Let us find analog i/p to OPAMP (Vin) for various digital inputs -

i) Suppose digital input is ABCD = 1000 then equivalent circuit becomes -



$$V_{in} = \frac{V \times 2R}{4R} = \frac{V}{2}$$

In this way, we can easily find the output of Voltage of R-2R ladder (Vin to OPAMP) for digital inputs.

→ When ABCD = 0010 then $V_{in} = V/8$

When ABCD = 0001 then $V_{in} = V/16$

The o/p of the complete D/A converter is calculated by using a summing amplifier equation -

i.e $V_0 = -R_f \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4} \right]$

$= -R_f \left[\frac{A}{2R} + \frac{B}{4R} + \frac{C}{8R} + \frac{D}{16R} \right] \times V$

$V_2 = \frac{B}{4}$, $V_3 = \frac{C}{8}$, $V_4 = \frac{D}{16}$

Specifications of D/A converter

Parameters used to describe the characteristics of D/A converters are –

i) **Resolution** – This is defined as the smallest possible change in the analog output as a result of a change in the digital input. This is also refered as step size and it is always equal to the weight of LSB.

$$\% \text{ Resolution} = \frac{1}{2^n - 1} \times 100$$

ii) **Accuracy** – It is a measure of the difference between the actual output voltage and the expected output voltage. It is specified as a full scale ~~or~~ output voltage.

Ex – $V_{FS} = 10\,V$ and accuracy $= \pm 0.2\%$

$$\text{Max. error} = V_{FS} \times 0.2\%$$

$$= V_{FS} \times \frac{0.2}{100} = 0.02\,V$$

iii) **Linearity** – This error is maximum deviation in step size from the ideal step size. This is indicated by ϵ. The linearity of a DAC is generally specified by comparing ϵ with Δ (step size)
(del)

iv) <u>Settling Time</u>

Time required for DAC o/p to go from zero to full-scale

The operating speed of DAC is specified by settling time. It is measured as the time for the DAC output to settle within $\pm \frac{1}{2} \Delta$ (step size) of its final value

v) <u>Temperature Sensitivity</u>

The analog output varies with temperature for any fixed digital input.

Change in the output with temperature is referred to as temperature sensitivity.

Unit of Temp. Sensitivity = ppm/°C.